up by this process. A sample of the material was therefore ground in an agate mortar and the finest particles were separated by stirrring up the material with water and allowing it to settle for 48 hours. The milky supernatant liquid was then removed and evaporated to dryness at low temperature. When sufficient material had been obtained in this way, the average size of the particles was determined with a micrometer microscope and they were found to be 0.0023 mm. in diameter. The density of this material was then measured and found to be 2.224, an increase of 2% over the previous value, this showing definitely the presence of extremely small pore spaces.

The facts, that (*a*) the index of the calcined flint agrees with that of cristobalite and (*b*) its density is much higher than that of the calcined chalcedony are readily explained by the presence of the impurities which are of such a nature as to act as a flux at high temperatures and thus to promote the growth of the cristobalite crystals.

[1] *Amer. J. Sci. New Haven,* **36,** 331(1913). See also Ferguson and Merwin, *Ibid.,* **46,** 417 (1917).

# *THE FREQUENCY-SENSITIVITY OF NORMAL EARS*

BY H. FLETCHER AND R. L. WEGEL

RESEARCH LABORATORIES OF THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY AND WESTERN ELECTRIC COMPANY, INC.

Communicated by J. J. Carty and F. B. Jewett, November 14, 1921

A large amount of work has been done during the last fifty years in an endeavor to determine in absolute terms the minimum amount of sound that the human ear can perceive. The results obtained by different investigators have varied throughout a very wide range. Two causes contributed to this; namely, that adequate apparatus was not available, and it was not appreciated that so-called normal ears vary so widely in their ability to hear.

The development of the vacuum tube, condenser transmitter, and thermal receiver has given us precision apparatus for work of this kind. In this investigation an air damped receiver was held tightly against the ear by means of a head band. It was actuated by an alternating current which was sent from a vacuum tube oscillator having a range of frequencies from 60 cycles to 6000 cycles per second. By means of a specially constructed attenuator the current entering the receiver could be varied approximately three millionfold. This was accomplished by moving a single dial switch.

By means of condenser transmitters and thermal receivers, this system was calibrated so that from the reading of the attenuator dial switch and the electric current entering it, the alternating pressure impressed upon

the ear cavity could be determined in dynes per square centimeter. This calibration was checked by two methods employing entirely different apparatus.

The measurements were made in a room which was especially constructed to eliminate all outside noises. The top, the bottom and the sides of this room were built of a number of alternate layers of loose felt and sheet iron, the final inside layer being felt covered with cheese cloth. It is extremely important that all noise interference be eliminated for this kind of work.

To make a measurement the vacuum tube oscillator was set to give the desired frequency. The attenuator dial was then moved until the sound from the receiver reached the threshold of audibility. Measurements were made upon 93 normal ears. The average of all these measurements is shown in figure 1 by the heavy line. The results of previous observers are also shown on this figure. It was necessary to use the logarithmic scale for pressures due to the large range of values involved. In figure 2 the curves show the variation of the female ears from the average. A similar set of curves for the male ears shows practically the same result. The average of the two sets was the same within the precision of the test. The probable error of observation was less than one-fifth the probable deviation of a single observer's results from the average. The peaks shown are real but vary greatly from one individual to another which make the average curve free from any noticeable peaks.

Audiograms for people of various types of deafness show striking differences in their relative frequency sensitivities. It is expected to make a complete report of work done along this line in the very near future. It is sufficient here to give from our general experience the amount of sound volume in the speech range that is required to make people of various degrees of deafness hear. Persons who have normal hearing require approximately 1/1000 dynes per square centimeter in order to hear sounds in this range. Persons who require a pressure variation of 1/10 dynes per square centimeter are called slightly deaf. Those who require one dyne are partially deaf but can usually follow ordinary conversation. Those who require 10 dynes belong to that class who use ear trumpets or deaf sets to amplify the speech waves. A pressure variation of approximately 1000 dynes can be felt and produces a sensation of pain. It is practicable to assume that people who experience no auditory sensation at these pressures are totally deaf.

This shows that among people who can follow ordinary conversation there is a range in ear sensitivity of more than 1000 and among people who are noticeably deaf there is another range of 1000 making a total range of more than a million for people who can hear or be made to hear by means of amplifying devices.

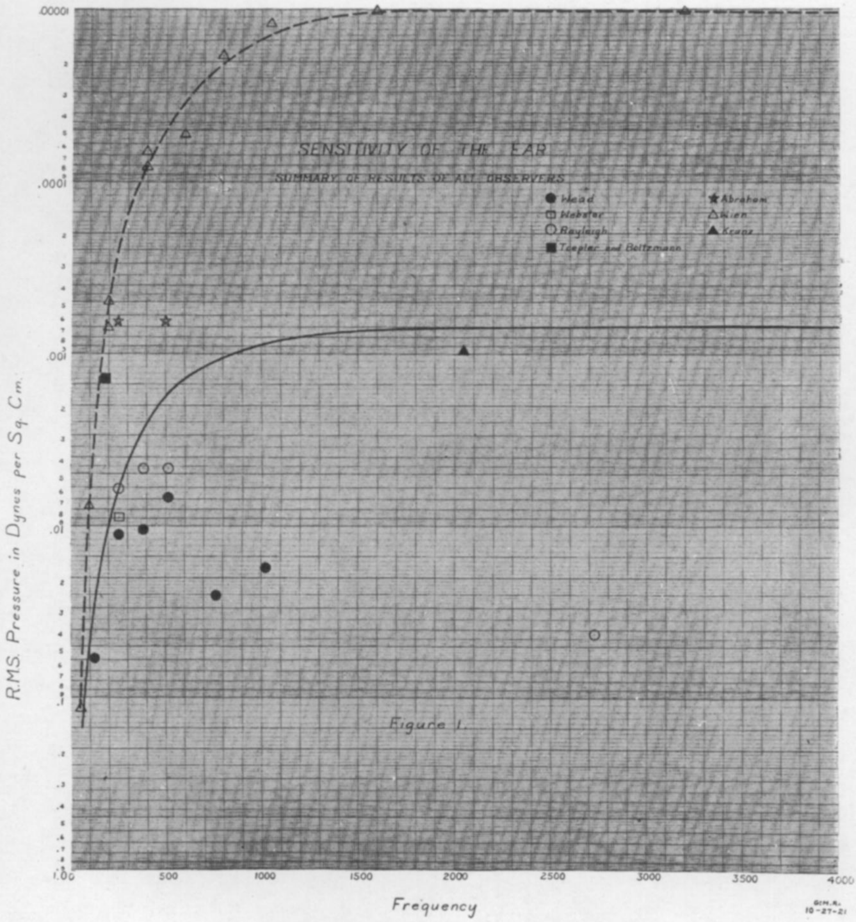
SENSITIVITY OF THE EAR
SUMMARY OF RESULTS OF ALL OBSERVERS
Head
Webster
Rayleigh
Toepler and Boltzmann
Abraham
Wien
Kranz
.00001
.0001
.001
.01
.1
1.00
500
1000
1500
2000
2500
3000
3500
4000
R.M.S. Pressure in Dynes per Sq. Cm.
Frequency
G.M.R.
10-27-21

Figure 1.

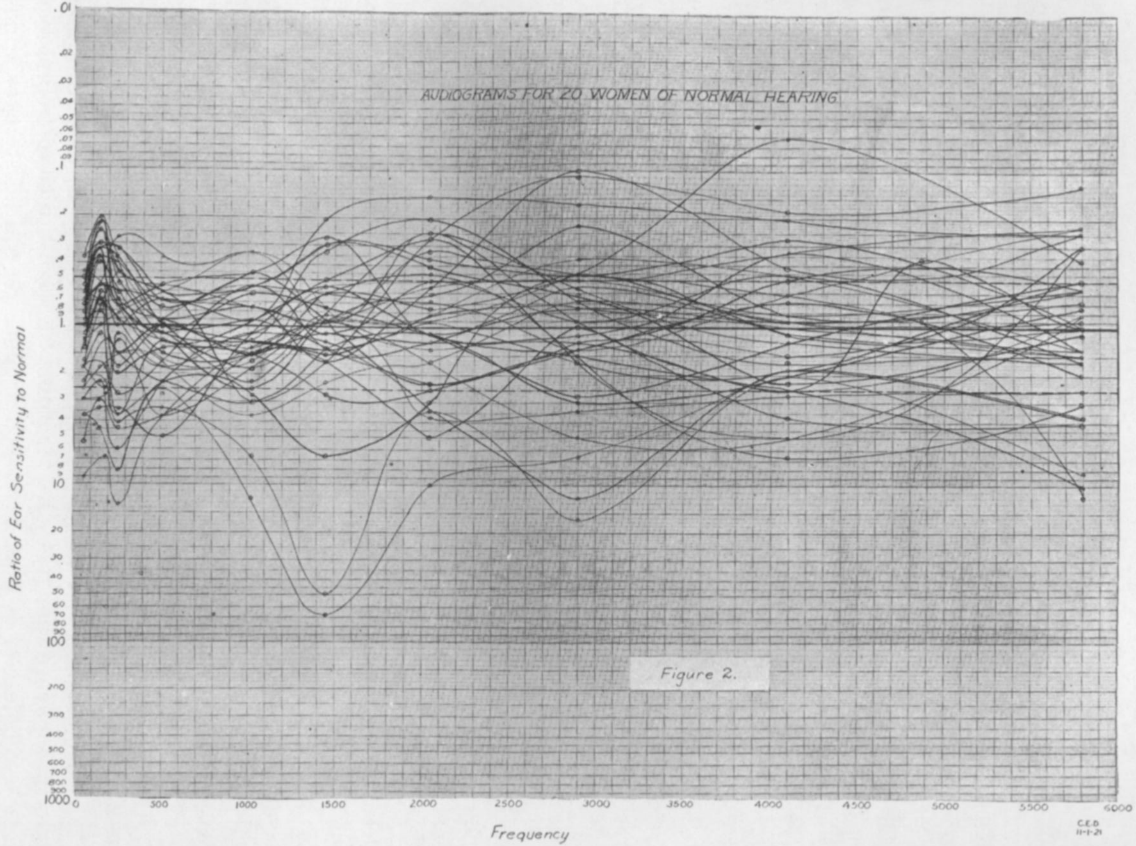
AUDIOGRAMS FOR 20 WOMEN OF NORMAL HEARING
Ratio of Ear Sensitivity to Normal
Frequency
C.E.D
11-1-21

Figure 2.